Spitzer Legacy Survey of the Cygnus-X Region

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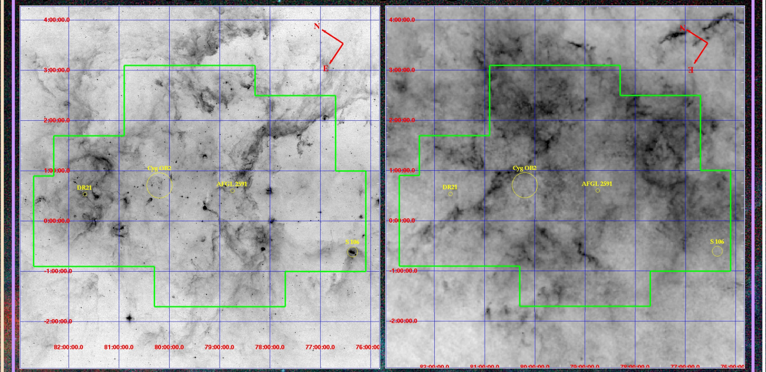
Abstract

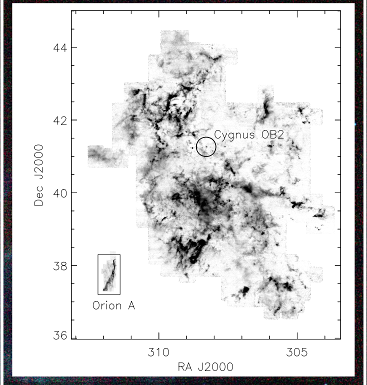
We describe the recently accepted *Spitzer* Legacy program that will survey the Cygnus-X region, a massive star formation complex containing the richest known concentration of massive protostars and the largest OB associations in the nearest 2 kpc. This unbiased survey of 24 sq degrees in Cygnus-X with the IRAC and MIPS instruments will have the sensitivity to detect young stars to a limit of 0.5 $M_{\odot}$. With this survey we will 1) analyze the evolution of high mass protostars with a large and statistically robust sample at a single distance, 2) study the role of clustering in high mass star formation, 3) study low mass star formation in a massive molecular cloud complex dominated by the energetics of ~100 O-stars, 4) assess what fraction of all young low mass stars in the nearest 2 kpc are forming in this one massive complex, and 5) provide an unbiased survey of the region and produce a legacy data set which can be used in conjunction with future studies of this region (e.g., with Herschel and JWST). The Cygnus-X survey will be an important step in constructing one of *Spitzer*'s greatest legacies: surveying with high sensitivity and spatial resolution a representative sample of Galactic star forming regions, from Bok globules to complexes containing millions of solar masses of gas and hundreds of O-stars. The data will be made available to the astronomical community in the form of images, source catalogs, and 3-70 µm photometry. We present the plans for the *Spitzer* Cygnus-X observations, and initial results from previous *Spitzer* and ground-based optical imaging of the survey field.

Spitzer Cygnus-X Survey Region



The above figures show the 24 square degree region to be surveyed, outlined in green. The MIPS fast scan mode will be used, and IRAC will map the area with 3×12sec HDR frames. The image on the left is the 8 µm *MSX*-A image of the Cygnus region, and the image on the right is the 2MASS extinction map (Bontemps et al. 2007). The locations of DR21, Cygnus OB2, AFGL 2591, and S 106 are indicated. The images are plotted in Galactic coordinates.

FCRAO ^{13}CO Map



The FCRAO ^{13}CO 1→0 map (Simon in prep), showing the distribution of the molecular gas relative to Cygnus OB2 and the relative size of Orion A if it were at 1.7 kpc.

The Cygnus-X Region

The Cygnus-X region is one of the brightest regions of the sky at all wavelengths and one of the richest known regions of star formation of the Galaxy. It contains as many as 800 distinct H II regions, a number of Wolf-Rayet and OIII stars and several OB associations. The association near the center of the complex, Cygnus OB2, was known to be large from optical observations (Reddish et al 1966, Massey & Thompson 1991). Subsequent IR observations indicated that Cygnus OB2 contains 2600±400 OB stars and ~100 O-stars, with a total stellar mass that could be as high as 10^5 $M_{\odot}$ (Knödlseder 2000, Comerón et al. 2002; Hanson et al. 2003).

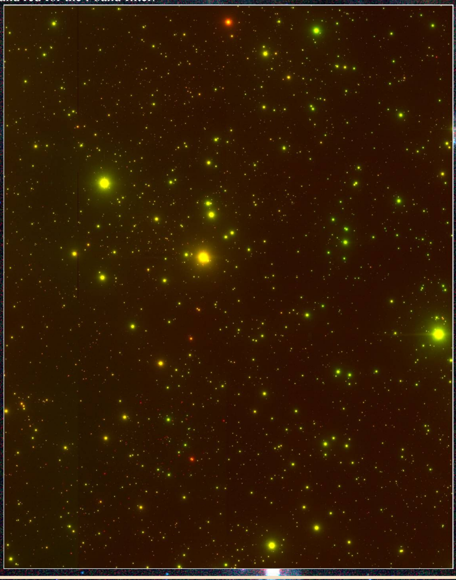
Cygnus-X also contains one of the most massive molecular complexes of the nearby Galaxy with a total mass of $3{\times}10^6$ $M_{\odot}$ (Fig. 1; Schneider et al. 2006). Cygnus-X has been long argued to be the superposition of a number of star-forming regions (Dickel et al. 1969). However, a detailed comparison of ^{13}CO 2→1 and 1→0 emission with *MSX* images led Schneider et al. (2006, 2007) to conclude that the molecular clouds in Cygnus-X form connected groups, and that the Cyg OB2 and OB1/OB9 associations directly heat the molecular material in Cygnus-X. The implication is that the majority of objects seen in this region are located at the same distance, i.e., that of the OB2, OB1 and OB9 associations at ~1.7 kpc. This includes sources like DR21 and S106, formerly estimated at 3 kpc and 600 pc, respectively, and implies that Cygnus-X is largely composed of a single 200 pc diameter, $3{\times}10^6$ $M_{\odot}$ complex. Thus, it has 3× the combined mass of the molecular clouds within 500 pc of the Sun, in a region 1/5 the diameter.

Given the high rate of high-mass star formation in Cygnus-X, as demonstrated by the existence of 40 massive protostars in regions such as DR21, DR21(OH), W75N, and AFGL 2591, Cygnus-X is thus the most active, rich, and massive star-forming complex within 2 kpc from the Sun. In addition, the close association of a rich OB cluster such as OB2 with a massive molecular complex is exceptional. We are probably witnessing an OB association that is growing while still embedded in its molecular complex. The mass is much larger than other nearby molecular clouds with OB associations such as Orion A (10^5 $M_{\odot}$; Bally et al. 1987), M17 ($3{\times}10^5$ $M_{\odot}$; Elmegreen et al. 1979) or Carina ($2{\times}10^5$ $M_{\odot}$: Schneider & Brooks 2004). Consequently, Cygnus-X appears to be giving birth to the largest OB association within 2 kpc.

Optical Survey

We are performing an optical survey of Cygnus-X using Keplercam on the 1.2m at the Whipple Observatory. The survey will include the Sloan r′ and i′ and Hα. The UKIDSS survey will achieve *J*, *H*, *K* magnitudes of 20, 19.1, and 19, respectively. We will use these data to assemble SEDs of sources from 0.6 to 70 µm will be used to classify the sources in terms of YSO class, or main sequence type. The optical data will provide additional constraints and allow more accurate fits of YSO models.

Our first observing run was in July 2007, approximately 15 hours of time was spent on the field over six nights. We are close to completing the i′ filter, and imaged selected small fields in all three filters. We will apply again in 2008 to complete the survey. Below is a sample image from a ~1°×1.5° section of the survey field near DR21, with green for the r-band and red for the i-band filter.



High Mass Star Formation

All potential sites of star formation in Cygnus-X – the densest clumps within molecular clouds – are detected in a complete, unbiased survey (~12 deg^2) using the CS 2→1 and N_2H^+ 1→0 lines (Schneider et al. 2007, see figure to the right). Most of the clumps show substructure, revealed by wide-field 1.2 mm continuum imaging (3 deg^2) with the MAMBO-2 camera (11″ resolution). In total, 129 protostellar dense cores (diameter ~0.1 pc; mass 4 – 900 $M_{\odot}$; Motte et al. 2005, 2007) were detected from which 40 are likely to be the precursors of massive OB stars. Half of these are high-luminosity IR sources (like DR21, W75N, AFGL2591, and S106IR), but the other half are either weak or even not detected by *MSX* at 8 µm. These IR-quiet objects have very powerful outflows traced by intense SiO emission and therefore represent a newly recognized evolutionary stage of high-mass star formation.

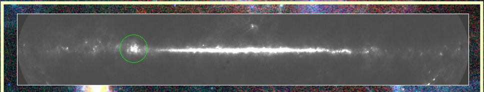
With this *Spitzer* survey, we will address the following questions:

• **What is the nature of the IR-quiet protostars?** The IR-quiet sources are not detected by *MSX*, but *Spitzer* is ~600× more sensitive at 8 µm. Two of the 17 IR-quiet cores in Cygnus-X are detected in existing MIPS data at a low level flux at 24 µm, but the vast majority are not covered in previous observations. The deep *Spitzer* observations are needed to detect these objects between 3 and 70 µm and study their SEDs.

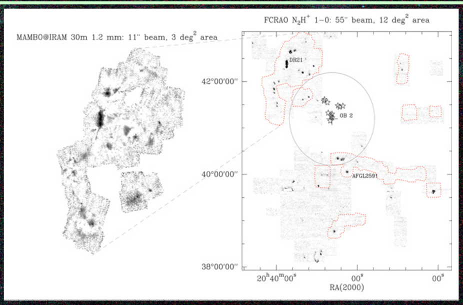
• **How do the SEDs of high-mass protostars evolve with time?** We will use *Spitzer* photometry from 3 to 70 µm together with our 350 µm (SHARC2) and 1.2 mm (MAMBO-2) data, and ultimately, with Herschel fluxes from 75 to 520 µm, UKIDSS *J*, *H*, *K* photometry, and SCUBA2 fluxes at 850 µm. This will produce SEDs spanning 1 to 1200 µm and provide well-constrained luminosities of high-mass protostars. These SEDs will be invaluable for guiding the development of models of high mass protostellar evolution.

• **What is the duration of the observed evolutionary stages?** The unbiased approach will provide unique results on the statistical properties of high-mass stars from their earliest phases of formation (IR-quiet protostars) to the main sequence (OB stars). With the hypothesis that star formation is a continuous process in Cygnus-X, the duration of the different stages (IR-quiet and IR-bright protostars, HII regions) relative to OB star lifetimes will be derived.

• **What is the incidence of clusters around high-mass protostars?** *Spitzer* has the sensitivity and resolution to detect clusters of low mass stars around the high mass protostars. We will determine the number and density of low mass stars surrounding the massive stars as a function of their evolutionary stage. With this we can assess whether clusters are necessary for the onset of massive star formation or if low and high mass stars form coevally in clusters, thereby testing theories that require clusters of low mass stars to form massive stars (e.g., Bonnell et al. 2004).



The Cygnus-X survey region is circled above in the DIRBE 140 µm image showing the Galactic Plane.



Left: The MAMBO-2 1.2 mm map of the region surrounding DR21. Right: The FCRAO N_2H^+ map of the Cygnus-X region near OB2. The relative position of the MAMBO-2 map is indicated. The dotted red lines show the extent of the MAMBO maps, the circle the extent of Cygnus OB2. The N_2H^+ data show the positions of dense cores which are the likely sites of high mass star formation. The MAMBO data show the cores with higher angular resolution; 129 protostellar cores have been identified (Motte et al. 2005; 2007).

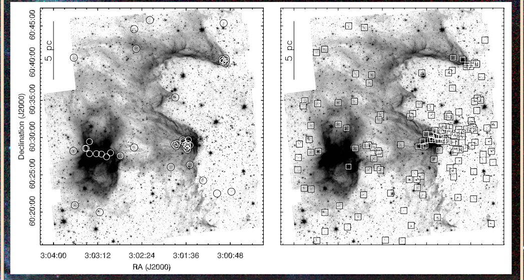
Low Mass Star Formation

Although high mass stars may dominate the energetics of the Cygnus-X complex, the vast majority of stars produced in all star forming regions are low mass stars; these stars contain most of the stellar mass. The huge concentration of molecular mass and high mass star formation in the Cygnus-X region suggest that it is the largest nursery of low mass stars in the nearest 2 kpc, potentially producing 10^5 stars – more than all the molecular clouds within 500 pc of the Sun. Using methods developed by our team members to identify and classify young stellar objects (Allen et al. 2007), we will produce a census of the low mass protostars and pre-main sequence stars in the complex. These observations will be sensitive to 1 Myr pre-main sequence stars with masses of 0.2 $M_{\odot}$.

With this census, we will measure the number and spatial distribution of protostars and pre-main sequence stars with disks. In contrast to massive stars, low mass stars form in a range of environments. *Spitzer* observations show that even for molecular cloud complexes within OB associations, as many as 40-60% of the low-mass stars are forming away from dense clusters (Allen et al. 2007; Megeath et al. 2007, Gutermuth et al. 2007). We will study the demographics of where low mass stars form in Cygnus-X (isolation, groups, or clusters); this will inform studies of more distant OB associations in the Galaxy and others.

The Role of Feedback in a Massive OB star/Molecular Cloud Complex

The evolution of massive star forming complexes such as Cygnus-X is driven by the energetics of the massive stars. *Spitzer* observations of bright-rimmed clouds in smaller OB associations such as W5 (see figure below) show clusters of young stars and protostars concentrated near the cloud surfaces. This geometry suggests a wave of induced star formation. We will search for similar structures, and assess the fraction of stars being formed at the cloud surfaces by triggering. These data will provide unique insights into processes inside starburst galaxies, where swarms of super star clusters may be compressing the associated ISM (Keto et al. 2005) .



Spitzer/IRAC images of the W5 region at 2 kpc. These images show the cloud surfaces shaped into the “Mountains of Creation” by external OB stars (West of the frame). In the left panel, the circles show the distribution of IRAC identified protostars (Class 0/1), in the right panel, the squares show the distribution of IRAC identified young stars with disks (Class II) (Allen et al. 2005). These show that much of the star formation is concentrated on the edge of the cloud, and also suggest a sequence of star formation, with the older class II source extending away from the cloud into the HII region, while the protostellar (Class 0/1) objects are concentrated at the cloud edge. This is indicative of a wave of star formation triggered by the compression of pre-existing cores in the molecular gas (Megeath & Wilson 1997). We will look for similar structures in Cygnus-X.

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Background image: 3 color *MSX* image of the Cygnus-X region

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